Idaho National Engineering and Environmental Laboratory

DOE Advanced Reactor Research

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Nuclear Safety Research Conference
Washington DC

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DOE's Advanced Reactor Work Encompassed by…

- Advanced Fuel Cycle Initiative
- Generation IV
- Major research areas
  – Fuels
  – Materials
  – System design & evaluation
  – Energy conversion & hydrogen
- Examples of Advanced Reactor R&D
  – High temperature reactor modeling
  – Particle fuels modeling, fabrication, and irradiation testing
  – Nuclear data
  – Thermochemical hydrogen production
- Summary

The National Energy Policy Recommends:

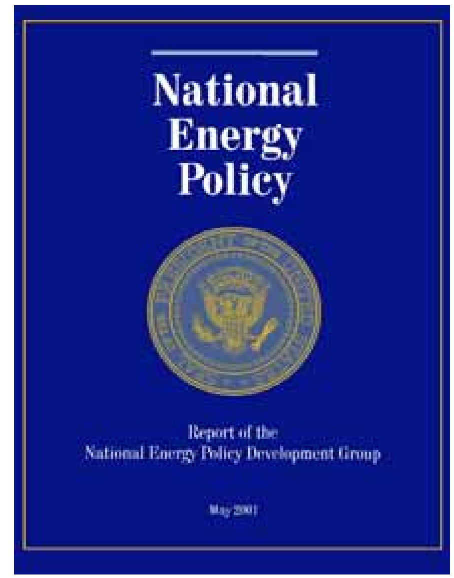
"The expansion of nuclear energy in the U.S.", and to

"Develop the next generation technology – including hydrogen," and that

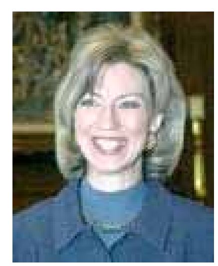
"The U.S. should consider technologies…to develop reprocessing and fuel treatment…that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant"

– ***Vice President Cheney, and the Secretaries of State, Energy, Transportation, Interior, Commerce, Treasury and Agriculture, and heads of EPA and OMB, among others***

May 2001



http://energy.gov/HQPress/releases01/maypr/national_energy_policy.pdf



Advanced Fuel Cycle Goals

The goal of the DOE NE AFCI is to develop fuel cycle technology that:

- ***Enables recovery of the energy value from commercial spent nuclear fuel,***
- ***Reduces the cost of geologic disposal of commercial spent nuclear fuel,***
- ***Reduces the inventories of civilian plutonium in the U.S.,***
- ***Reduces the toxicity of high-level nuclear waste bound for geologic disposal, and***
- ***Enables more effective use of the currently proposed geologic repository so that it will serve the needs of the U.S. for the foreseeable future.***

January 2003


Report to Congress
on
Advanced Fuel Cycle Initiative:
The Future Path for Advanced Spent Fuel Treatment and Transmutation Research

Prepared by
U.S. Department of Energy
Office of Nuclear Energy, Science, and Technology
January 2003

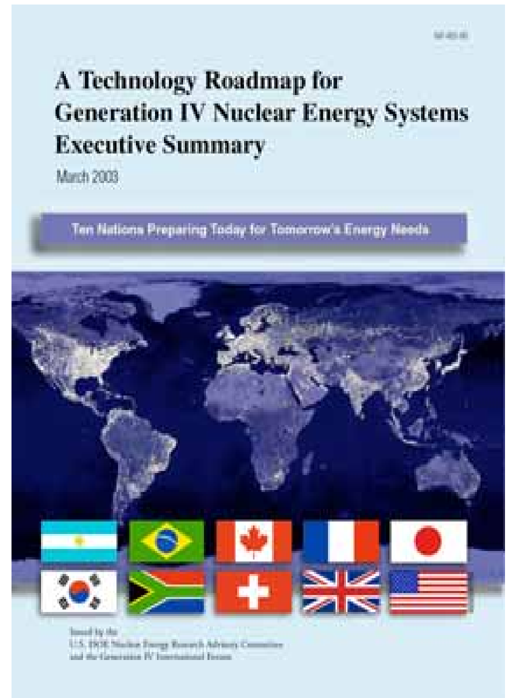
http://www.nuclear.gov/AFCI_RptCong2003.pdf

Generation IV Technology Goals

Generation IV Program goals are aimed at developing advanced nuclear systems that are deployable by 2030 or earlier and:

- ***Have adequate fuel resources and reserves for many years***
- ***Are economically competitive with all energy alternatives***
- ***Are even safer and more reliable than Generation III technology***
- ***Are exceptionally proliferation resistant.***

March 2003



http://gif.inel.gov/roadmap

Integrated Generation IV/AFCI Programs

- *Technical Integration: R. Bennett/R. Schultz (INEEL) & J.D. Smith (SNL)*
- *National Technical Directors*
  - *Energy Conversion Systems: P. Pickard (SNL)*
  - *Fuels & Cladding: K. Pasamehmetoglu (LANL)*
  - *Materials: W. Corwin (ORNL)*
  - *Separations: J. Laidler (ANL)*
  - *System Design & Evaluation: H. Khalil (ANL)*
  - *Transmuters: M. Capiello (LANL)*
- *Product Managers*
  - *New Generation Nuclear Plant: F. Southworth (INEEL)*
  - *Supercritical Water Reactor: J. Buongiorno (INEEL)*
  - *Gas-Cooled Fast Reactor: K. Weaver (INEEL)*
  - *Lead-Cooled Fast Reactor: D. Crawford (ANL) & C. Smith (LLNL)*
  - *Sodium-Cooled Fast Reactor: J. Roglans (ANL)*
  - *Molten Salt Reactor: C. Forsberg (ORNL)*

Generation IV R&D Needs…

	Fuels	Materials	Energy Conversion	System Design & Evaluation
NGNP & SCWR	_Demonstrate fuel fabrication processes & QA approach* _Demonstrate & model fuel irradiation performance* _Identify waste repository needs	_Confirm materials adequate for high temps in vessel*, internals, insulation, control rods*, etc. _Develop & demonstrate high temperature heat exchanger materials*	_Identify & demonstrate most efficient means to produce H_2 _Demonstrate thermally-efficient intermediate heat exchanger* (IHX)	_Develop & verify analysis methods, data, & codes _Perform analysis & trade studies to select reference design (prismatic or pebble-bed)* _Demonstrate passive safety performance operability _Confirm economic viability
GFR & LFR	_Confirm fuel fabrication techniques _Demonstrate fuel irradiation performance _Develop capability to fabricate carbide & nitride fuels** _Demonstrate fuel & matrix material recyclability**	_Demonstrate materials compatible with operational conditions _Demonstrate materials operational in corrosive environment	_Investigate H_2 production cycles _Perform confirmatory demonstration of Brayton cycle _Develop IHX technology _Develop and demonstrate balance-of-plant	_Develop & verify analysis capability _Optimize safety systems & confirm reactivity control and transient behavior _Develop correlations and properties for working fluid _Demonstrate passive safety performance capability _Reduce uncertainty of heat transfer & fluid flow regimes*** _Define deployment strategy & economic models***

* NGNP specific **GFR specific ***LFR specific

Modular Helium Reactor Cutaway

Upper plenum - hot plume mixing - "LOF"

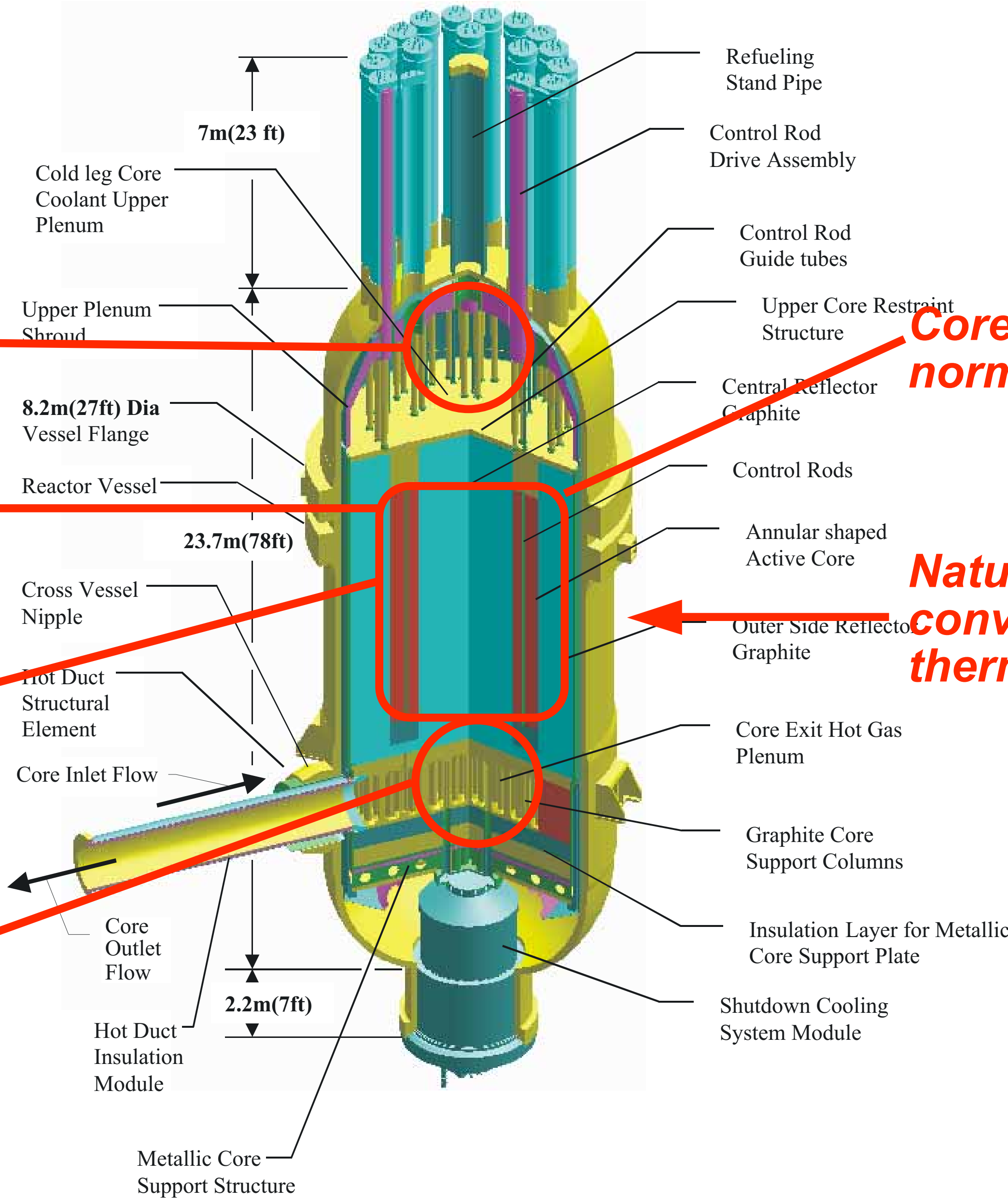
Core - depressurized cooldown

Flow between hotter/ cooler channels - "LOF"

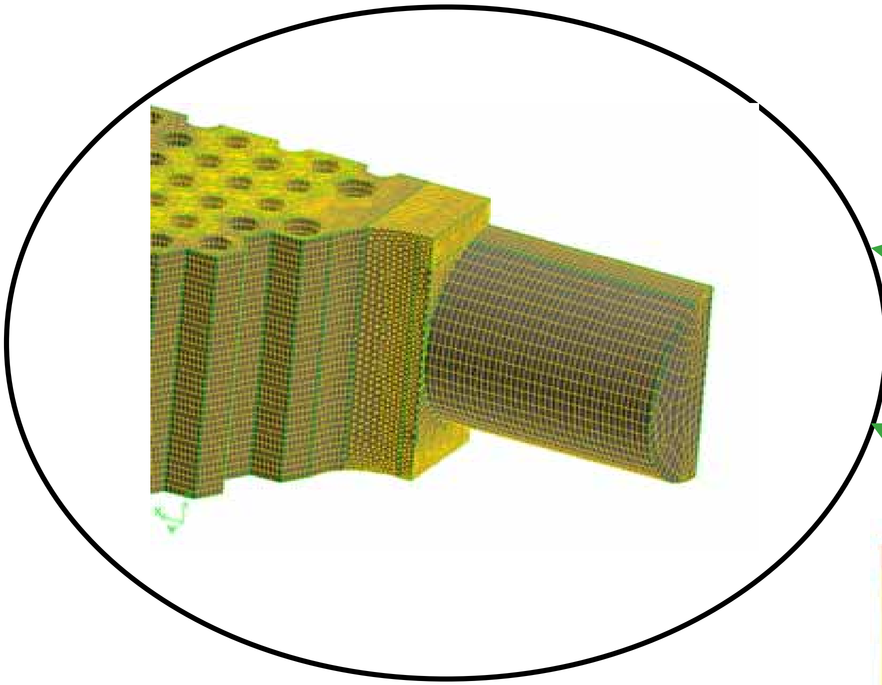
Lower plenum - hot jet mixing

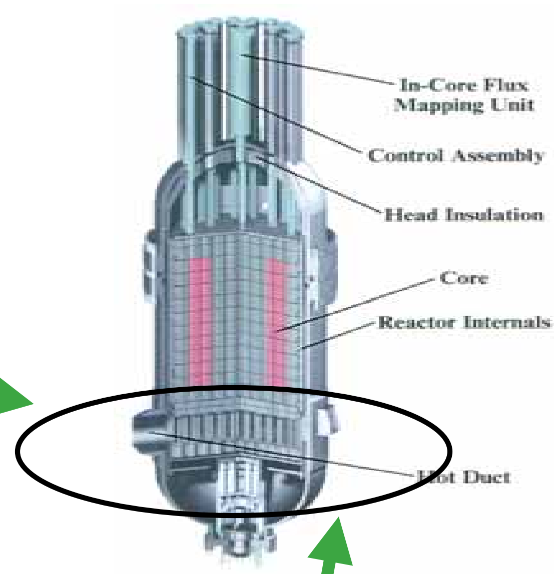
Core flow - normal operation

Natural convection and thermal radiation

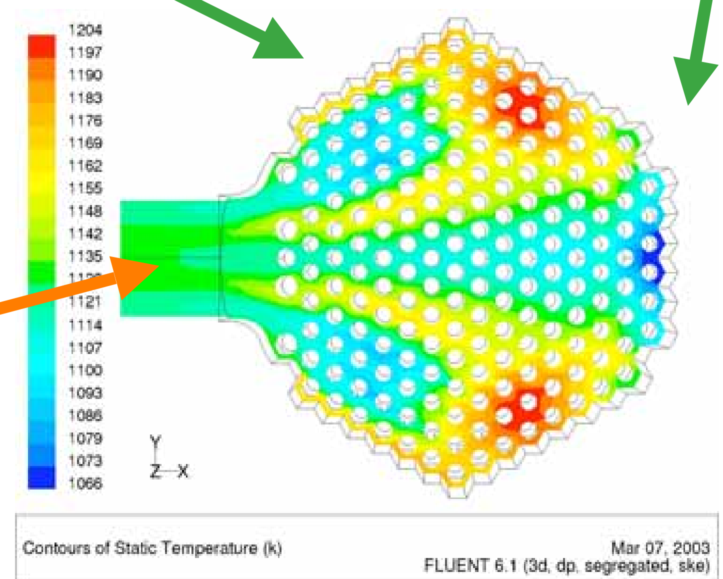


GT-MHR Lower Plenum Analysis to Study "Hot-Streaking"…





Fluid (Flow) Domain

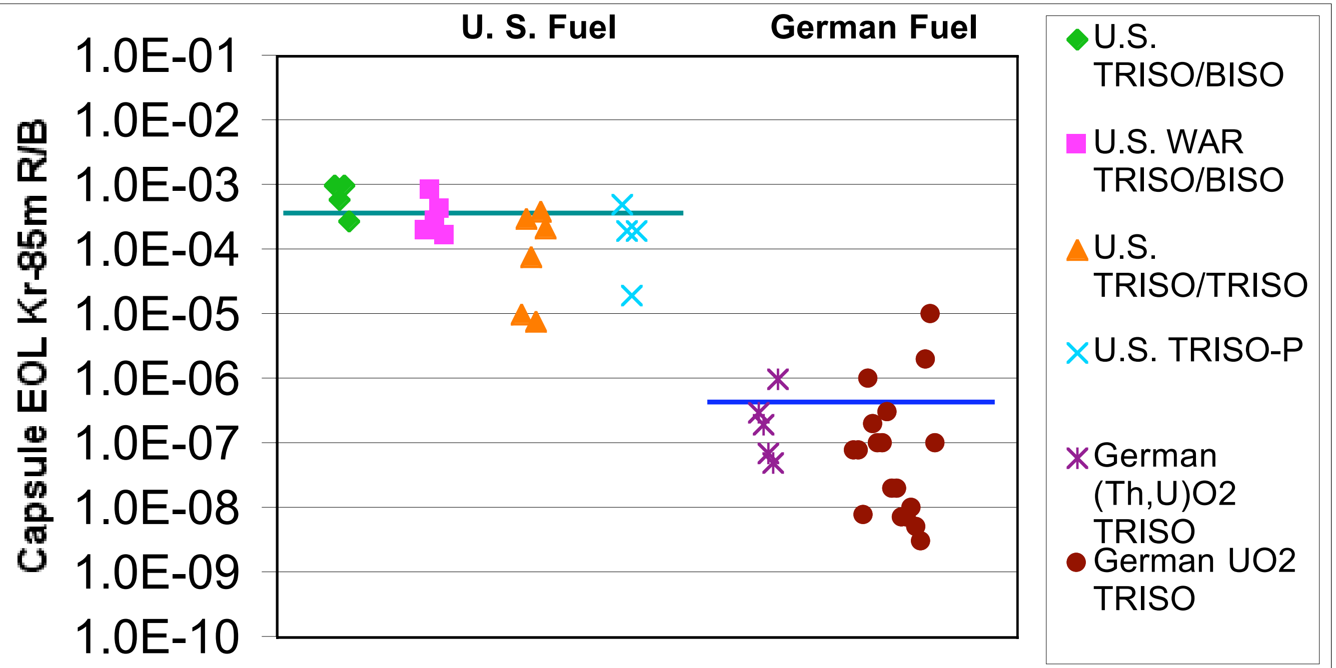


Potential "hot-streaking" in hot duct

Courtesy of Fluent

Why Additional Fuel Work is Needed

Comparison of German and US EOL Gas Release Measurements from Numerous Irradiation Capsules

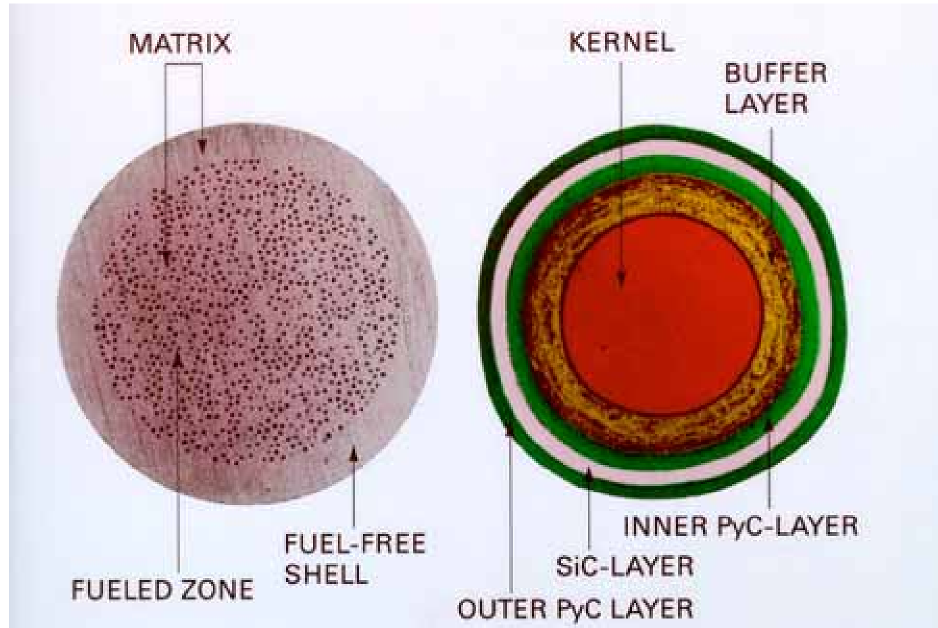


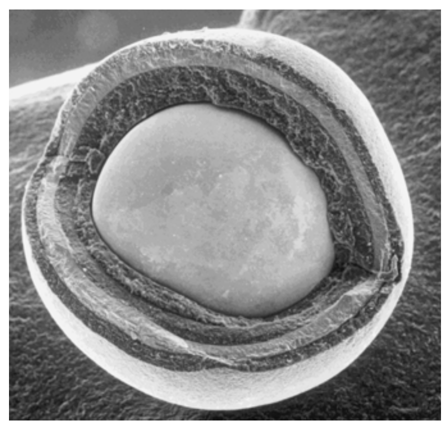
	U.S.	German
Irradiation temperature (C)	930 - 1350	800 - 1320
Burnup (%FIMA)	6.3 - 80	7.5 - 15.6
Fast fluence (10^{25} n/m^2)	2.0 - 10.2	0.1 - 8.5

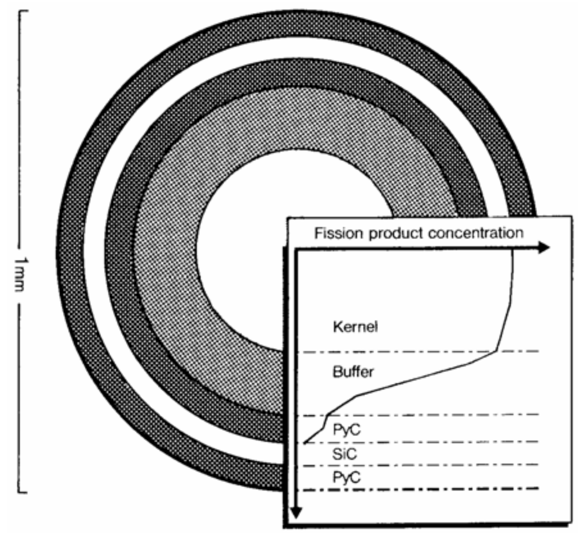
Only German fuel had excellent EOL performance

Goals of Particle-Fuel Modeling Effort

- *Develop an integrated mechanistic state of the art fuel performance model that*
  - *Models relevant failure mechanisms observed in coated particle fuel*
  - *Explains past poor performance of US coated particle fuel*
  - *Can be used as a tool to predict performance of future coated particle fuel designs*
  - *Help to provide greater linkage between fuel performance and fuel product and process specifications used to manufacture the fuel*



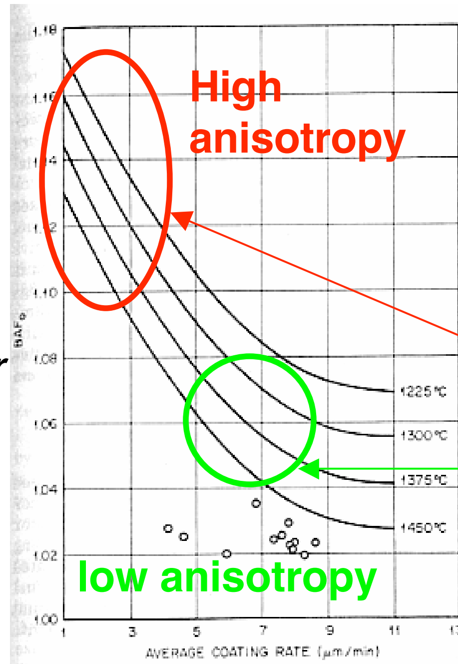




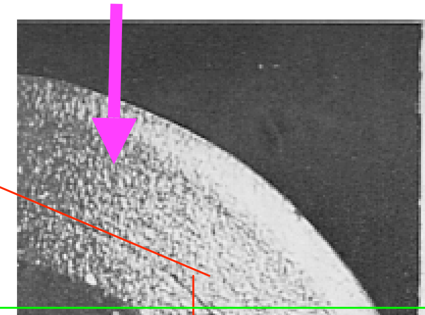
INEEL

Impact of Fabrication Differences on Irradiation Performance

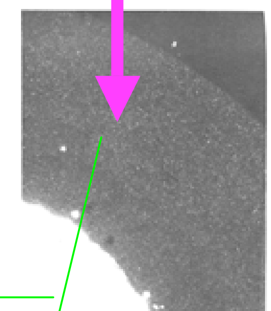
- *Important differences in manufacture of IPyC that dramatically influence behavior under irradiation.*
  - *Germany --> higher coating gas concentrations --> higher coating rate --> less anisotropy and better survivability under irradiation*
  - *US --> lower coating gas concentrations --> lower coating rate --> higher anisotropy causing cracking under irradiation which leads to failure of the SiC*
  - *May explain much of the difference in irradiation performance of US and German fuel.*

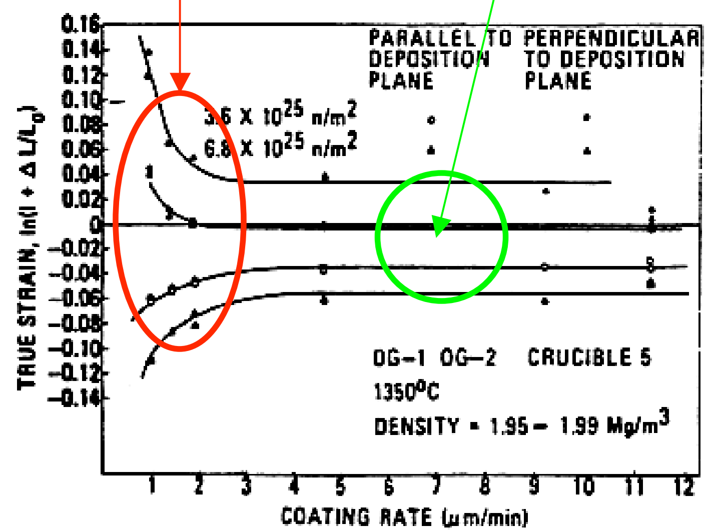


PyC produced at low coating rates

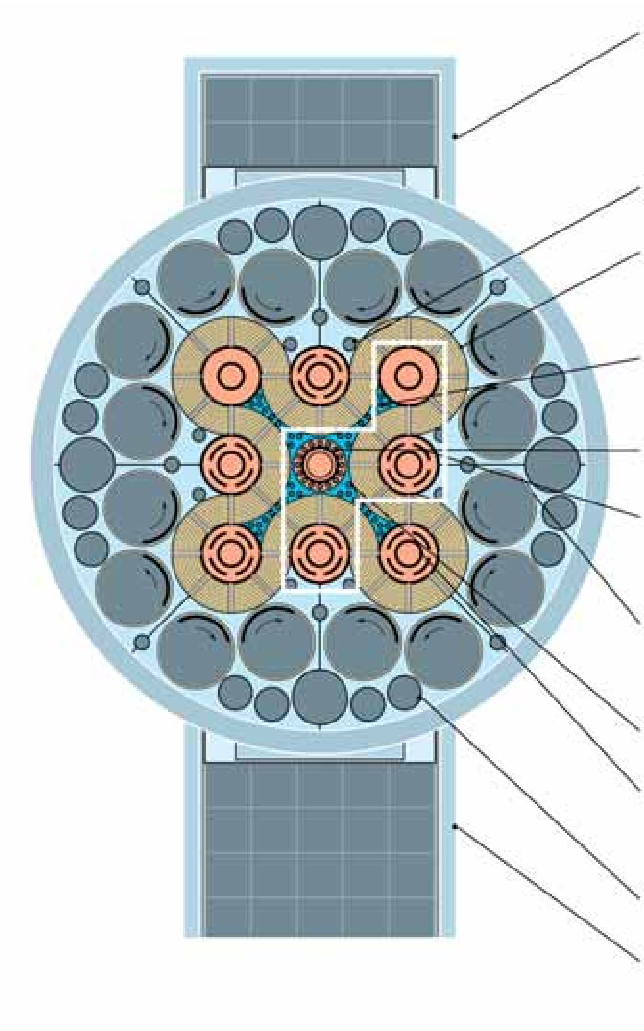


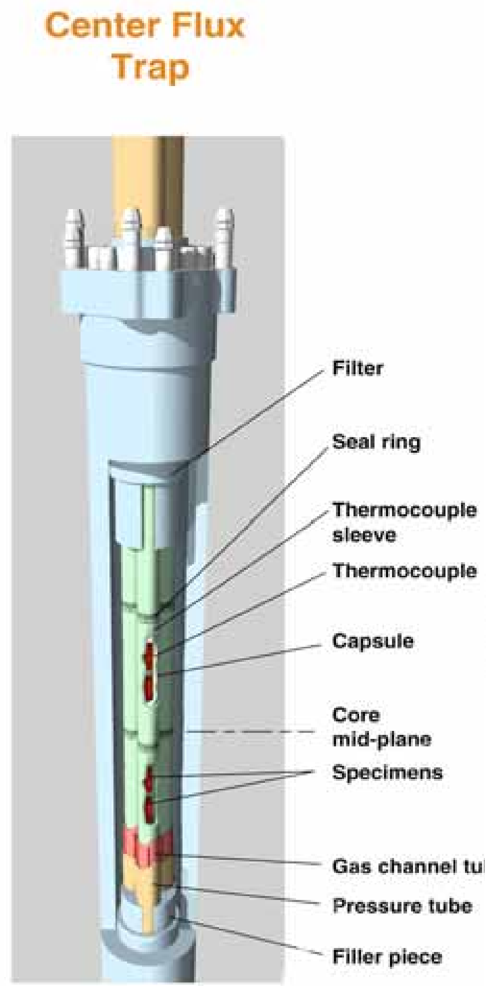
PyC produced at higher coating rates

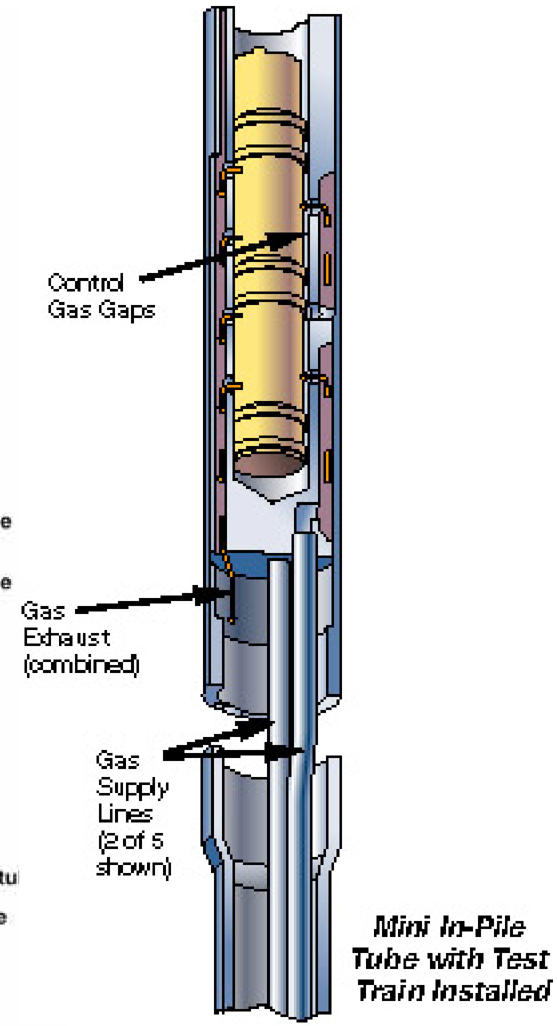




ATR has large volumes for irradiation and numerous irradiation locations which provide great flexibility for irradiation testing

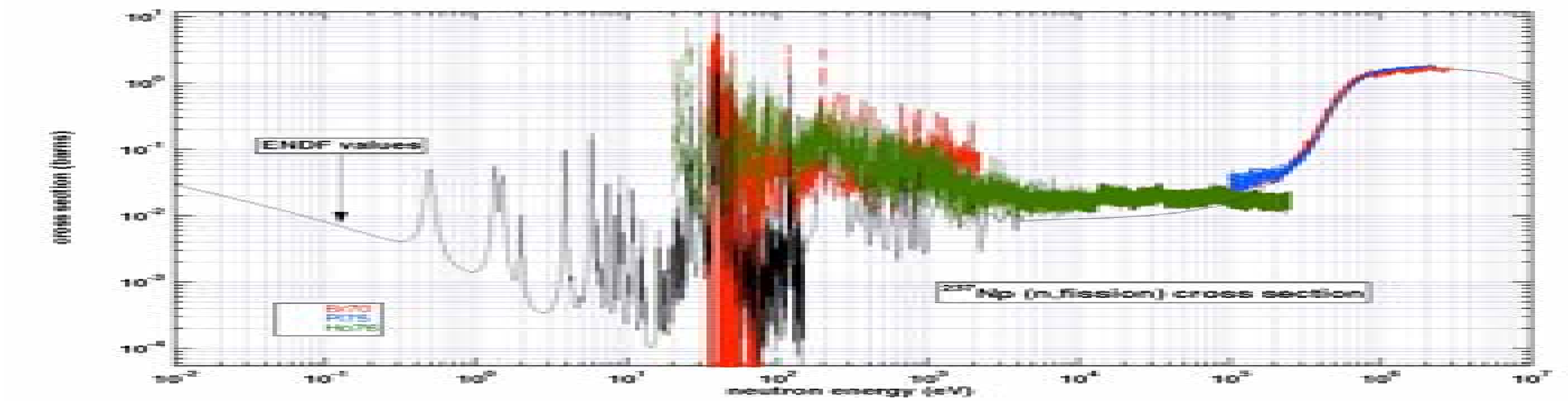






Nuclear Data Measurements are Needed for High-Burnup Cores and Advanced Nuclear Energy Systems with Recycled Fuel

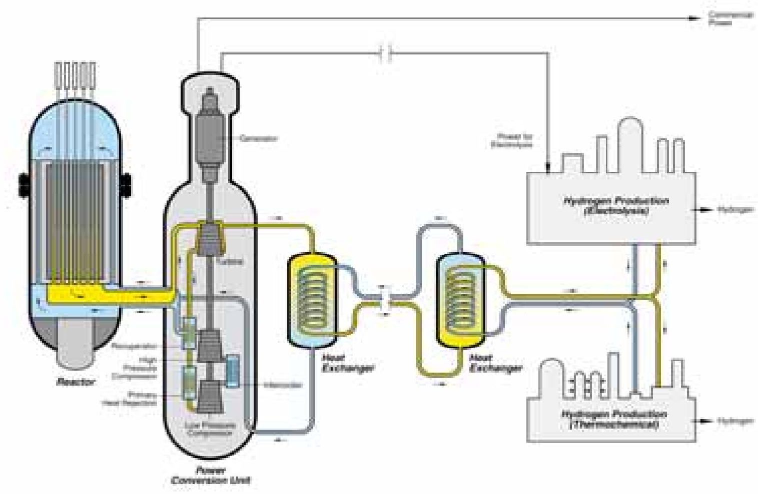
--When "minor actinides" become major constituents--



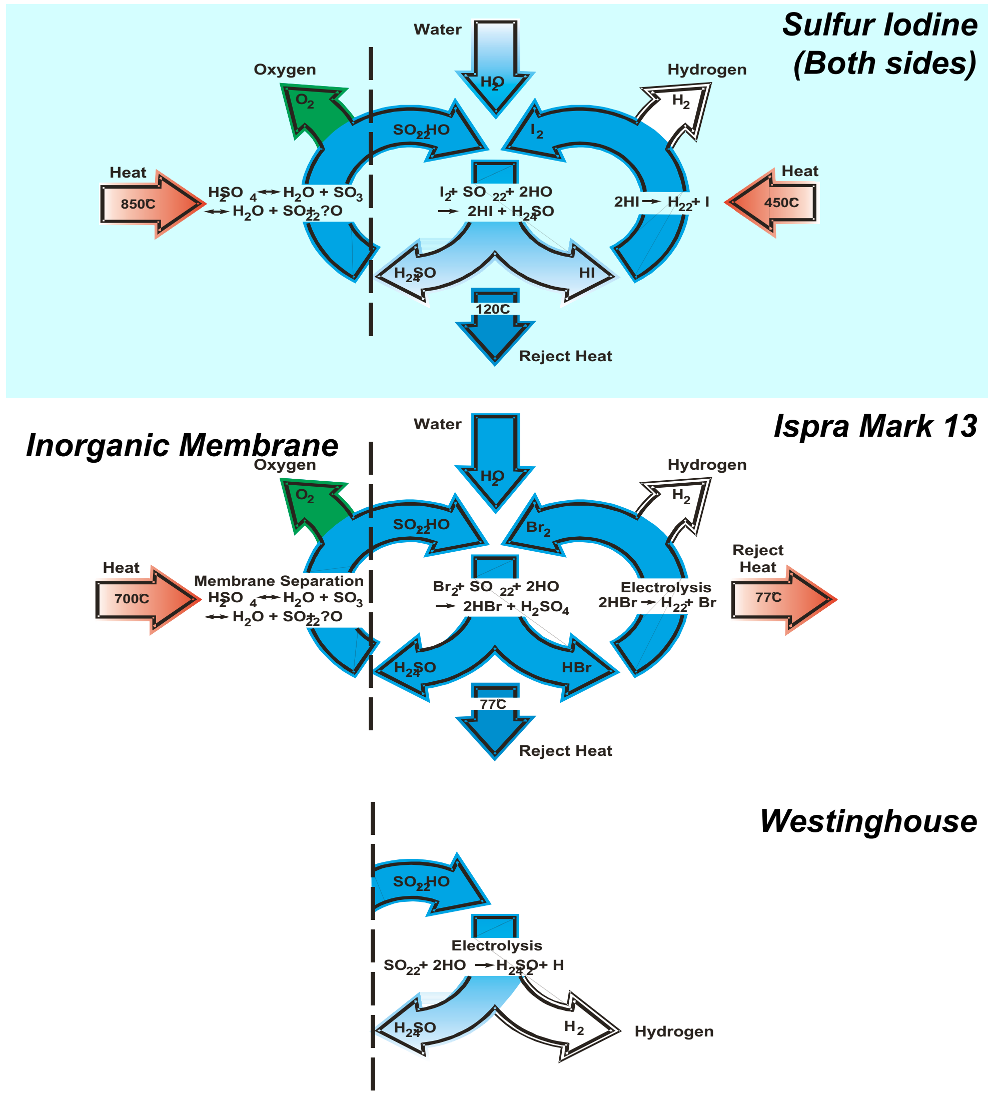
- ***Cross-section uncertainties, and gaps in the measured data, are currently too large for many of the minor actinides***
- ***These data uncertainties result in large uncertainties in calculated core physics performance (criticality, burn-ups reactivity…) and safety parameters (reactivity feedback coefficients, control system reactivity worth…)***
- ***Example: Np-237 (n_1 fission)***
  - ***substantial differences in measured data***
  - ***gaps in the measured data***
  - ***measured data is not always consistent and the ENOF evaluation***
  - ***critical mass of Np-237 is 60±20 kg***

High Temperature Nuclear Reactors May Contribute to Hydrogen Production

- ***Energy security and environmental quality motivate hydrogen as a alternative to oil as a transportation fuel***
- ***Hydrogen demand is already large and growing rapidly***
  - ***Heavy-oil refining***
  - ***Consumes 5% of natural gas for hydrogen production***
- ***Bridge to the hydrogen economy***
  - ***Hydrogen fuel cells***
  - ***Zero-emissions transportation fuel***
  - ***Distributed energy opportunity***
  - ***Large-scale, zero emissions hydrogen production is an enabling technology***
- ***Water is the preferred hydrogen "fuel"***
  - ***Electrolysis using off-peak power***
  - ***High-temperature electrolysis***
  - ***High-temperature thermochemical water splitting***

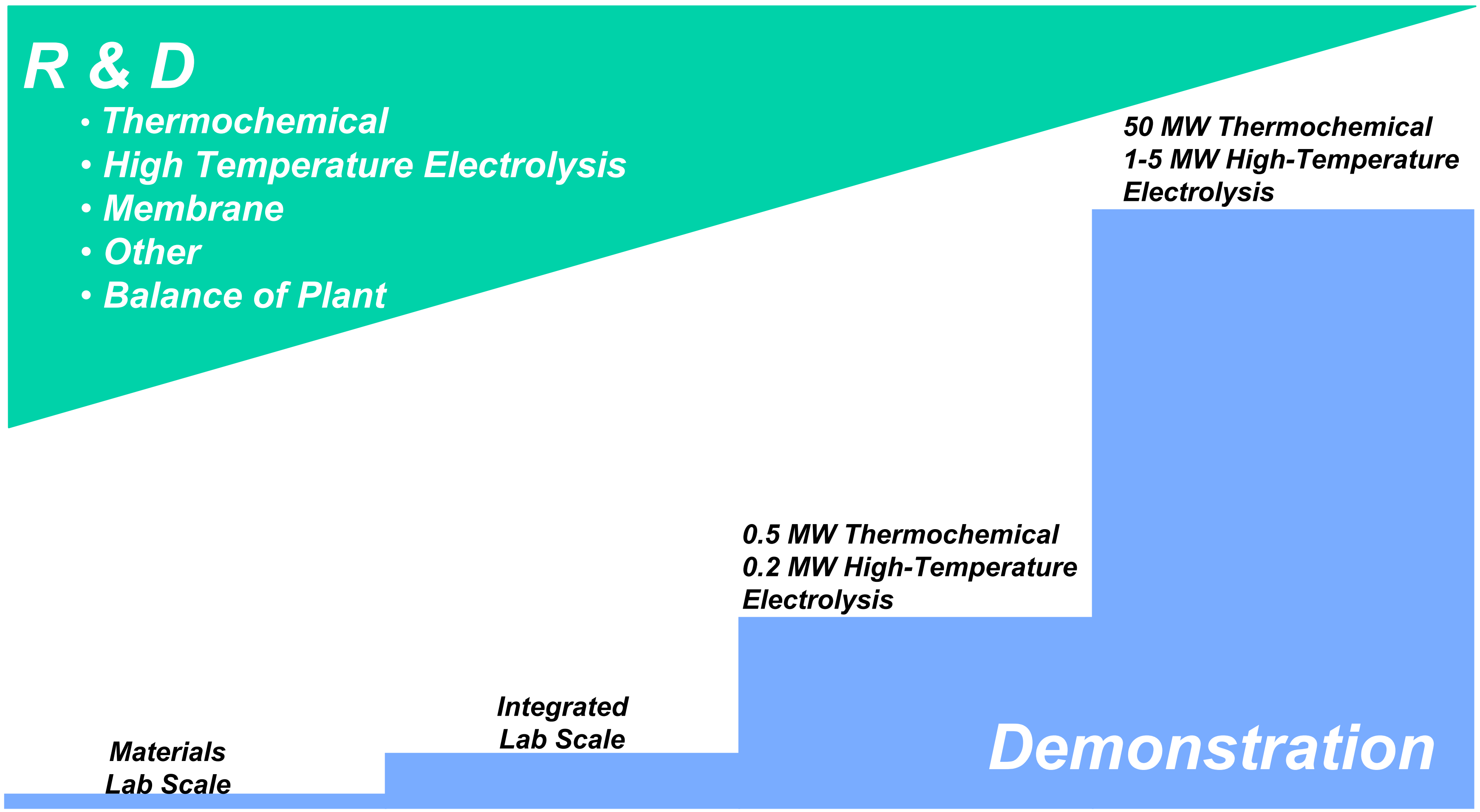


Sulfur Family of Thermo-Chemical Cycles for Hydrogen Production



(courtesy of Charles Forsberg – ORNL)

Nuclear Hydrogen Production Scale-Up Requirements



Summary..

- *Each Generation IV system has a unique set of technical challenges that stem from fuels, materials, energy conversion, and system design & evaluation energy considerations*

- *The DOE Advanced Reactor R&D Program involves contributors at national laboratories, universities, industry, and international partners.*

- *References:*
  - *Generation IV Roadmap: http://gif.inel.gov/roadmap*
  - *Advanced Fuel Cycle Initiative: http://www.nuclear.gov/AFCI_RptCong2003.pdf*